

## PERFORMANCE EVALUATION OF NATURAL RUBBER MODIFIED BITUMINOUS MIXES

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### ABSTRACT

Natural Rubber Modified Bitumen (NRMB) is one of the most commonly used modified bitumen in Kerala, which is produced by adding latex or rubber powder to the ordinary bitumen at specific conditions. The early development of distress in the pavements with the conventional mixes revealed the need of design specifications based on performance tests. The performance tests are those tests which simulate the field conditions and measure the response of the bituminous mix in terms of stress, strain and deflection. The present study evaluates the Natural Rubber Modified Bituminous mix properties by conducting different performance tests. Study includes the different tests on aggregates, bitumen and NRMB mix. Different performance tests conducted on NRMB mix are Marshall Test, Indirect Tensile test, Moisture Susceptibility, Repeated Load Test. All the tests were carried out for the aggregate gradation of Bituminous Concrete Grade II. The specimens were made for the lower limit, middle limit and upper limit of the gradation, in order to study the effect of gradation of the aggregates in the properties of bituminous mix. In all the performance tests the specimens prepared for the middle limit of the aggregate gradation showed better results than that of the others. The NRMB mix is showing excellent rut resistance. From the Repeated Load Test it is clear that the fatigue life increases with the increase in resilient modulus and decreases with the increase in the % air void and initial strain. The overall performance of NRMB mix is better compared with that of the ordinary bituminous mix.

**KEYWORDS:** Natural Rubber Modified Bitumen, Marshall Stability Test, Indirect Tensile Test, Moisture Susceptibility, Fatigue Life

### INTRODUCTION

An efficient and adequate system of transportation is inevitable for the development of any country. Of the different means of transportation, road transport is the most significant one. Design, construction and maintenance of roads are given prime importance in the development of the infrastructure of a country. A high traffic intensity in terms of overloaded commercial vehicles and significant variations in daily and seasonal temperature of the pavement have been responsible for early development of distress symptoms like ravelling, undulations, rutting, cracking, bleeding, shoving and pot holing of bituminous surfacing. A factor which causes further concern in India is very high and very low pavement temperature in some parts of the country. Under these conditions flexible pavement tend to become soft in summer and brittle in winter. There comes the importance of polymer modified bitumen. Natural Rubber Modified Bitumen (NRMB) is one of the common modified binders used for flexible pavement construction.

The way the additive usually influences the bitumen characteristics is by dissolving into certain component fractions of the bitumen itself, spreading out its long chain polymer molecules to create an inter-connecting matrix of the polymer throughout the bitumen. It is this matrix of the long chain molecules of the added polymer that modifies the physical properties of the bitumen. Because of the thermoplastic nature of the polymers, some polymers will actually break up into their constituent molecular blocks at the high temperatures, during mixing and laying, and recombine into their polymer chains at lower temperatures, i.e. ambient temperatures. The polymer additives do not chemically combine or change the chemical nature of the bitumen being modified, apart from being present in and throughout the bitumen. What polymers will do is change the physical nature of bitumen; they are able to modify such physical properties as the softening point and the brittleness of the bitumen. Elastic recovery/ductility can also be improved.

The performance of a pavement depends on different factors like geometry, climate, loading and material characteristics. So it is unrealistic to think that the performance can be captured in a single test. For this reason there came a set of performance based specifications, which gives a better understanding of bituminous mix response and damage mechanisms of the materials used. Performance tests simulate field conditions and measure the response of flexible pavement such as stress, strain and deflection and it is used in situations involving moderate to high traffic. Performance tests can be used to relate laboratory mix design to actual field performance. Major types of failures considered for performance evaluation are fatigue, rutting, low temperature cracking, moisture susceptibility etc. The objective of the study is to evaluate the performance of polymer modified bituminous mixes through laboratory investigations. The performance evaluation of lower limit, middle limit and upper limit of NRMB mix is also done to study about the significance of gradation of the aggregate in mix performance.

## LITERATURE REVIEW

Some of the factors affecting the performance behaviour of the bituminous mixes are compaction method, mix type, temperature, loading frequency, rest period, gradation limits airvoids etc. The compaction method used for the preparation of the specimen will affect the fatigue characteristics. To modify the ordinary Marshall Compaction method, modified Marshall Compaction method is established. It is said to have the potential to replace the gyratory compactors used in Superpave mix design (Awanti, 2006). The rest period is important while giving the dynamic load because wheel loads are not acting on the same point but distributed across the cross section and there is some delay between the applications of wheel load on a same point due to the axel length of a vehicle and also the head way between vehicles. Rest period always increases the fatigue life of the bituminous mix. (Maria, 2006).

- **Different Types of Failures in Flexible Pavements**
  - **Rutting**

Wheel path rutting is a result of accumulation of small amount of deformation that is caused during each load application. There can be two types of rutting, one is due to weak bituminous mixture and the other is due to weak subgrade. Rutting due to weak bituminous mixture is due to low shear strength of the mixture to resist the repeated loadings. The binders having more cohesive characteristics are able to provide more shear strength to the binders. The aggregates having high angle of internal friction will also give more shear strength to the mixture. Rutting due to poor subgrade is considered as a structural problem (Anderson, 1995).

- **Fatigue Cracking**

Fatigue cracking is the most common type of cracking which occurs due to relative movement of pavement layers. The fatigue cracking arises from the repeated tensile strain due to traffic loading. The maximum tensile strain will be at the bottom layer and once the crack is initiated it propagates upwards causing gradual weakening of the structure. Fatigue cracking will cause total failure of the pavement that may lead to pot holes etc. Factors affecting fatigue cracking are heavy loads, material problems, subgrade drainage, stripping of underlying layer, resilient property of materials at bottom layer etc.

- **Moisture Susceptibility**

When critical environmental condition, poor materials, high traffic etc come together, then premature failure of the pavement will occur due to stripping of binder from the mineral aggregates (Ray Brown, 2001). There are three mechanisms of failure due to moisture susceptibility. They are Loss of cohesion of binder, loss of adhesion between the aggregate, the binder and fracture of individual aggregate particles. This distress generally begins at the bottom of the pavement and then progress upwards. The factors affecting moisture sensitivity of the bituminous mixture are type of the mix, characteristics of the binder and aggregates and the environmental conditions during and after the construction of the pavement (Brain, 2005).

- **Studies on Performance Characteristics**

A study was conducted on fatigue characteristics of bituminous concrete mix modified with recycled plastic in India. The tests were conducted on ordinary bituminous mixture and also plastic modified mixture. Marshall Stability tests and indirect tensile tests were conducted to determine the optimum binder content. Repeated load test was done using an accelerated loading instrument fabricated in the Bangalore University (Punith, 2005).

In a project conducted to study the behaviour of low quality coated aggregates explains the different properties of aggregates used for road construction (Nagiem, 2006). Sharply angular and roughly textured aggregates produce more stable mix and crushed faces in aggregates reduce rutting. Resistance to deformation under 'long-term' loading conditions is dependent on both interparticle and binder friction. Two contributing factors to the resistance of materials to compressive loads are internal friction and cohesion. Angle of internal friction increases with proportion of crushed particles in the blend. The performance tests used to study the mix characteristics are shear box test, repeated load axial test and repeated load indirect tensile test. From the repeated load indirect tensile test the stiffness modulus of the mix was found. Axial deformation was the parameter used for comparing the test results of different mixes for the repeated load axial test.

Steyn and Verhaeghe conducted a study on permanent deformation characteristics of HMA mix, in 2006. To find the fatigue and rutting properties they tested both field and lab mixes. The mix types include continuously graded, semi and open graded mixture and stone mastic asphalt mixture with unmodified and modified binders. The tests conducted were Transportek Wheel Tracking Test (TWTT), Marshall Stability Test, static and dynamic creep test and shear test. It was observed that shear deformation is the dominant mode of deformation causing rutting in pavements. It is more sensitive to temperature and rate of loading than volume change. The results were compared with field performance data. The results showed that the contact stress and surface temperatures are critical factors affecting the performance of an asphalt mix in terms of both fatigue and rutting.

In a study conducted in Bialystok Technical University, Poland in 2007, the rut and dynamic creep test were conducted on different type of asphalt mixtures to find the permanent deformation characteristics. Rolling compaction was used for the specimen preparation. Resistance to permanent deformation was tested before aging, after short term aging and after long term aging. The types of asphalt used are Ordinary asphalt, elastomer, plastomer and rubber modified asphalt. The type of asphalt mixtures considered were bituminous concrete, stone mastic asphalt mixture, Superpave mixture and porous asphalt mixture of two air void content percentage. The results proved that the resistance to permanent deformation depend upon the type of asphalt mixture and also the type of binder. The dense mixture showed more resistance than porous mixtures with modified bitumen. For same mixture types the one made with polymer modified bitumen showed more resistance to permanent deformation. The results are pointing out the fact that the performance of an asphalt mixture depends on both the type of mixture and type of binder (Piotr, 2007).

## CHARACTERISATION OF MATERIALS

The materials used in present study are given below:

- **Plain Bitumen:** 80/100 grade (PB 80/100)
- **Polymer Modified Bitumen:** Natural Rubber Modified Bitumen (NRMB) of grade 60/70
- **Aggregates and Filler:** Crushed granite coarse and fine aggregates and filler. 2% of the filler material whose particle size is less than 75 micron was replaced by Ordinary Portland cement.
- **Properties of Aggregates**

The tests conducted on the aggregates to study their properties included Specific Gravity, Impact Value, Crushing Value, Los Angeles Abrasion value, Combined Flakiness and Elongation index. Tests were conducted as per the relevant IS specifications. A minimum of three specimens were tested and the average of three close values was taken. The results of the tests on aggregates are shown in Table 1.

**Table 1: Aggregate Properties**

Property	Average Value	Specification	IS Code
Specific gravity - coarse aggregate	2.731	2.6 – 2.8	2386 (Part-III)-1963
Specific gravity - fine aggregate	2.645	2.6 – 2.8	2386 (Part-III)-1963
Impact value	21%	Max 24%	5640- 1970
Crushing value	28%	Max 30%	9376 – 1979
Los Angeles abrasion value	26%	Max 30%	10070 – 1982
Combined flakiness and elongation index	18	Max 25	2386 (Part-I)-1963

- **Properties of Binders**

The binders used for the study were PB 80/100 and NRMB 60/70. Natural Rubber Modified Bitumen (NRMB) was mostly in situ mixing of natural rubber latex with bitumen. For this, the bitumen was heated to about 140°C and small amounts (1%) of kerosene were added as viscosity modifier. To the boiling bitumen, natural rubber latex as specially

preserved field latex (about 2% by weight of bitumen) is added, stirred well and kept for about 2 hours for homogenization. The tests conducted on bitumen are Penetration Test, Softening Point Test, Ductility Test, Loss on Heating, Specific Gravity Test, Elastic Recovery Test, Separation Test. Results of the various tests conducted for PB 80/100 and NRMB 60/70 are given in Table 2 and Table 3.

**Table 2: Properties of PB 80/100 Grade Bitumen**

Property	Average Value	Specification	IS Code
Penetration	82	80-100	IS:1203-1978
Softening point (°C)	44	40-45	IS: 1205-1978
Ductility (cm)	79	Min 75	IS: 1208-1978
Loss on heating (%)	0.4	Max 1.0	IS:1212- 1978
Specific gravity	1.038	Min 0.99	IS:1202-1978

**Table 3: Properties of Natural Rubber Modified Bitumen (NRMB)**

Property	Average Value	Specification	IS Code
Penetration	66	50-89	IS:1203-1978
Softening point (°C)	50.6	Min 50	IS: 1205-1978
Loss on heating	0.44	Max 1.0	IS: 1212 - 1978
Elastic recovery (%)	40	Min 35	IS: 120-21978
Separation (°C)	1	Max 3	IS 15462: 2004

## BITUMINOUS MIX CHARACTERISTICS

The properties of bituminous mixes have much importance in the lifelong performance of a pavement. To study the mix characteristics it is important to study about the failures in the pavements and their characteristics. In this study rutting and fatigue failure are considered which are the two main distresses widely occurring in Indian pavements.

- **Experimental Framework**

The Marshall test, which is the conventional empirical method, was done to find the mix characteristics and also the optimum binder content. Indirect Tensile test was done to find the rutting potential of the mix and moisture susceptibility test will give the resistance to failure of the mix due to the exposure to moisture. Repeated load test, which is a dynamic test, will give the fatigue characteristics of the mix and the optimum binder content was found with respect to the resilient modulus. All the above tests were done for lower limit, middle limit and upper limit of the gradation of Bituminous concrete grade II to find the influence of variation in gradation in the mix characteristics.

- **Specimen Preparation**

All the tests were conducted for lower limit (LL), middle limit (ML) and upper limit (UL) of bituminous concrete grade II for the bitumen content 4.5, 5, 5.5, 6, 6.5 and 7% NRMB mix and for plain bituminous mix middle limit specimens were prepared using Modified Marshall Compaction method. For all tests a minimum of 3 specimens were tested and the average values were taken for the analysis.

- **Marshall Stability Test**

The Marshall Test is used in designing and evaluating bituminous paving mixes, and is widely applied in routine test programmes for the paving jobs. The major features of the Marshall method of designing mixes are to determine two important properties; strength and flexibility. Strength is measured in terms of the 'Marshall stability' of the mix which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. This temperature represents the weakest condition for a bituminous pavement in use. The flexibility is measured in terms of the 'flow value' which is measured by the change in diameter of the sample in the direction of load application between the start of load and the time of maximum load.

The test was conducted as per standard procedure. The properties like theoretical specific gravity ( $G_t$ ), the bulk specific gravity of the mix ( $G_m$ ), total air voids (Vv), Voids in Mineral Aggregate (VMA), Voids Filled with Bitumen (VFB), Marshall Stability and Flow value were find and given in the tables 4and 5.

**Table 4: Marshall Stability Test Results for NRMB Mix**

BC (%)	Gradation	Unit Weight (g/cc)	Voids with Bitumen (%)	Filled Bitumen	% Air Voids	Stability Value (kN)	Flow Value (mm)
4.5	LL	2.42	79.64	3.21	10.93	3.34	
	ML	2.42	79.70	2.85	14.73	3.15	
	UL	2.41	79.15	2.86	10.79	3.17	
5.0	LL	2.43	85.04	2.11	16.68	3.40	
	ML	2.43	87.22	1.81	20.01	3.03	
	UL	2.42	87.50	1.76	16.48	3.47	
5.5	LL	2.42	88.97	1.67	11.13	3.67	
	ML	2.42	89.98	1.50	16.21	3.09	
	UL	2.407	89.45	1.56	10.83	3.48	
6.0	LL	2.405	91.17	1.42	7.75	3.75	
	ML	2.38	87.23	2.09	11.08	2.93	
	UL	2.39	91.06	1.41	8.32	3.50	
6.5	LL	2.39	92.86	1.21	6.30	5.91	
	ML	2.36	86.41	2.40	6.98	4.64	
	UL	2.38	92.79	1.20	8.22	4.13	
7.0	LL	2.38	93.75	1.12	5.94	8.89	
	ML	2.37	94.04	1.06	6.71	6.36	
	UL	2.36	93.70	1.11	8.26	5.50	

**Table 5: Marshall Stability Test Results for PB Mix**

BC (%)	Unit Weight (g/cc)	% Air Voids	Voids Filled with Bitumen (%)	Stability Value (kN)	Flow Value (mm)
4.5	2.381	4.684	68.936	10.893	3.120
5.0	2.386	3.752	75.673	11.579	3.663
5.5	2.392	2.804	81.015	13.614	3.99
6.0	2.387	2.292	84.911	11.681	4.623
6.5	2.374	2.143	87.849	9.833	5.04
7.0	2.359	2.035	88.963	7.825	7.143

Optimum binder content for NRMB was found to be 5% and the maximum stability value and unit weight was shown by the middle limit specimen. Optimum binder contents for PB 80/100 was found to be 5.5% and at these binder

contents flow value and voids filled with bitumen were within the specified limits. The NRMB mix shows higher stability value and lower flow value than PB mix.

Analysis of variance (ANOVA) at 95% confidence level was done for stability values of lower limit and middle limit and also upper limit and middle limit. The null hypothesis is mean of the two groups are equal and the alternate hypothesis is the means are different. The null hypothesis is rejected in all cases. It means there is a significant difference between the stability value of aggregate gradation ML with that of LL and UL.

- **Static Indirect Tensile Strength Test**

Indirect tensile strength of the mix is a good indicator of rutting resistance of the mix. Rutting is one of the major causes of premature failure of the flexible pavement and so it should be considered in the design criteria. Indirect tensile testing involves applying a static compressive load across the diametrical axis of the cylindrical specimen. The mechanics of the test are such that a state of tensile stress is achieved across the diametrical plane. The load is applied at a rate of 5.08 cm/min until failure occurred. The ultimate load is obtained to calculate maximum indirect tensile strength.

Specimens prepared with NRMB and PB 80/100 were tested as per ASTM: D-4123-82(1995). The test was conducted for conditioned and unconditioned specimen. Conditioning consists of soaking the specimens in water maintained at 60°C for 24 hours and allowing them to cure at 25°C for one hour. The test is conducted at 25°C. Moisture susceptibility of bituminous mixes may also be determined in terms of TSR (Tensile Strength Ratio), which is expressed as the percentage of average static indirect tensile strength of the conditioned specimens to the average static indirect tensile strength of the unconditioned specimens.

Based on the maximum load carried by a specimen at failure in indirect tensile strength test, the indirect tensile strength in kPa was calculated the equation.

$$\text{Indirect Tensile Strength, ITS} = 2F/(\pi LD) \quad (1)$$

where F is the applied vertical load (kN), L is the mean thickness of the test specimen (m); D is the specimen diameter (m).

Results of the indirect tensile strength test on conditioned and unconditioned specimens for PB mix and NRMBB mix are given in Table 6 and 7.

**Table 6: Indirect Tensile Strength Test Results for PB Mix**

Binder Content (%)	ITS (kPa)		TSR (%)
	Unconditioned	Conditioned	
4.5	680.13	621.28	91.35
5.0	738.23	689.23	93.36
5.5	611.84	593.74	97.04
6.0	611.70	585.46	95.71
6.5	586.35	545.09	92.98
7.0	459.25	456.63	93.33

**Table 7: Indirect Tensile Strength Test Results for NRMB Mix**

<b>Binder Content (%)</b>	<b>Gradation</b>	<b>ITS (Kpa)</b>		<b>TSR (%)</b>
		<b>Unconditioned</b>	<b>Conditioned</b>	
4.5	LL	608.39	541.15	88.95
	ML	675.37	630.19	93.31
	UL	628.34	551.79	87.82
5.0	LL	692.34	650.79	94.00
	ML	782.21	758.48	96.97
	UL	702.33	661.66	94.21
5.5	LL	584.27	536.71	91.86
	ML	694.57	643.94	92.71
	UL	644.31	579.44	89.93
6.0	LL	502.33	441.79	87.95
	ML	592.35	532.62	89.92
	UL	554.78	482.57	86.98
6.5	LL	474.30	408.69	86.17
	ML	488.86	428.97	87.75
	UL	554.78	482.57	86.98
7.0	LL	424.93	356.57	83.91
	ML	449.04	378.78	84.35
	UL	429.21	361.72	84.28

The IDT strength of NRMB mix is greater than 440 kPa up to 6.5 % binder content. So according to IRC guidelines the NRMB mix has excellent rut resistance. The aggregate gradation ML is showing high IDT strength than that of LL and UL which shows the rut resistant potential for Middle Limit specimen is higher than the others. The maximum IDT strength is at 5% binder content, which is the Optimum Binder Content. NRMB mix is less moisture susceptible and has a better performance when compared to that of ordinary bituminous mix.

## REPEATED LOAD TEST

Pavement distress due to repeated bending or fatigue of flexible pavements is one of the common pavement problems throughout our country. To consider the fatigue properties of the bituminous mix in pavement designing procedure, it is necessary to find the fatigue behaviour of the bituminous mix under repeated dynamic load as in situ. The repeated load test will give the fatigue properties of the bituminous mix. It is a diametral dynamic load test in which the load is varied in a half sine wave pattern. The diametral fatigue test is an indirect tensile test on a cylindrical specimen in which a repeating compressive load is applied along the vertical diametral plane. This loading configuration will develop a reasonably uniform tensile stress in the specimen in the direction perpendicular to the load application and along the vertical diametral plane.

- Repeated Load Testing Apparatus**

Repeated load testing equipment, shown in Figure 1, available at the Transportation Engineering laboratory of NIT Calicut was used for conducting repeated load indirect tensile test. The equipment consist of a loading system, cooling system, loading frame, controlling system and a software part.



**Figure 1: Repeated Load Testing Apparatus**

The specimen was placed in the specimen holder diametrically and the top plate was placed over it. It was held in position by adjusting the horizontal clamps. Then the holder was kept exactly at the centre with respect to the loading shaft. Then the controlling system was switched on and the two horizontal and two vertical LVDTs were fixed. V1, V2, H1 and H2 were made zero by fine adjustment. Load is also set to zero. From the software part we can give the peak load, frequency, rest period etc. and also control the shaft movement. The load given was 20% of that of the ultimate indirect tensile strength at a frequency of 1 Hz. The specimens were tested for without rest period and with a rest period of 0.9 sec. The loading was stopped automatically when the required criteria is reached or when the specimen fails. The load applied and the deformations at specific intervals will be stored in a notepad file by the software which can be used for further calculation.

- **Fatigue Characteristics**

The different fatigue characteristics of the mixes are:

- Fatigue life ( $N_f$ )
- Resilient modulus ( $M_r$ )
- Initial tensile strain ( $\epsilon_i$ )

- **Fatigue Life ( $N_f$ )**

Fatigue life is the number of cycles to failure. It is also called flow number. To be more specific it is the number of cycles upto tertiary flow. The primary and tertiary flow can be differentiated from the secondary flow by the difference in the linear relation between cumulative permanent strain and number of cycles.

- **Resilient Modulus ( $M_r$ )**

The resilient modulus ( $M_r$ ) is the form of an elastic modulus, which can be defined as the ratio of applied stress to recoverable resultant horizontal strain. The values of resilient modulus can be used to evaluate the relative quality of materials and also can be used as an input to pavement design or pavement evaluation. The resilient modulus can be calculated as

$$\text{Resilient modulus in MPa, } M_r = P (0.27 + \mu_r) / H_r \cdot h \quad (2)$$

where  $P$  = repeated load (N)

$\mu_r$  = Resilient Poisson ratio which was taken as 0.45 at 30-32°C test temperature (Nunn 1995)

$h$  = height of specimen (mm)

$H_r$  = resilient horizontal deformation (mm)

- **Initial Tensile Strain**

Initial tensile Strain is the initial recoverable tensile strain. It is an indicator of the performance of a bituminous mix under repeated load.

$$\text{Initial tensile strain, } \varepsilon = \sigma (1 + 3 \mu_r) / M_r \quad (3)$$

Where,  $\sigma$  = maximum tensile strain at the center of specimen

ANOVA analysis is done between the fatigue life of the NRMB mix with rest period and without rest period at 5% binder content for all the gradations. It shows that the increase in fatigue life of the mix when rest period is introduced is significantly high. From the Repeated Load Test results it is clear that the fatigue life increases with the increase in the resilient modulus and decreases with the increase in % air voids and initial tensile strain as shown in figure 2, figure 3 and figure 4 and there is a significant difference between the fatigue life of NRMB mix and PB mix. The specimens prepared with middle limit aggregate gradation are showing better fatigue life than the lower limit and upper limit specimens.

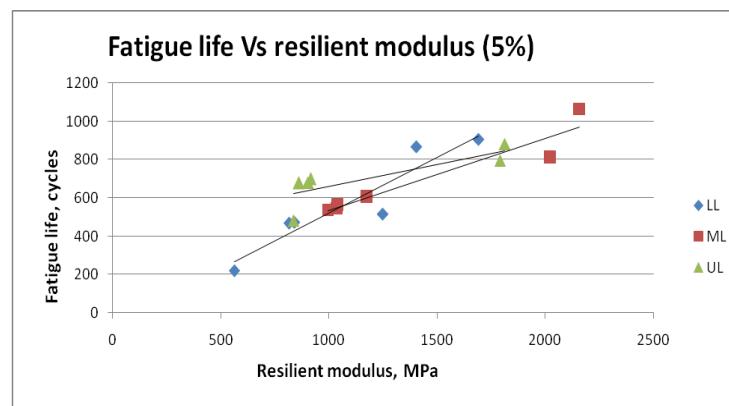


Figure 2: Fatigue Life Vs Resilient Modulus for NRMB Mix at 5% BC

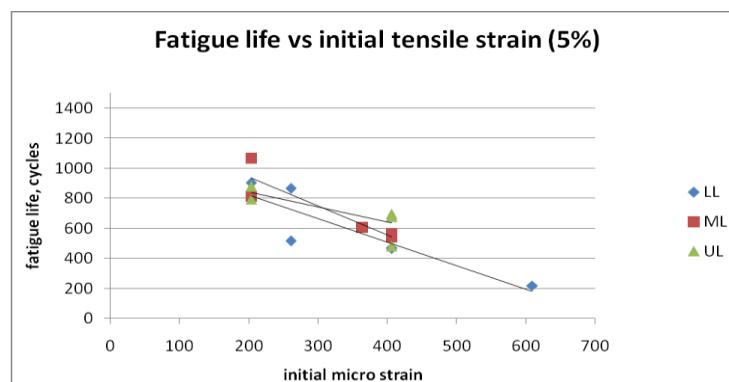


Figure 3: Fatigue Life Vs Initial Tensile Strain for NRMB Mix at 5% BC

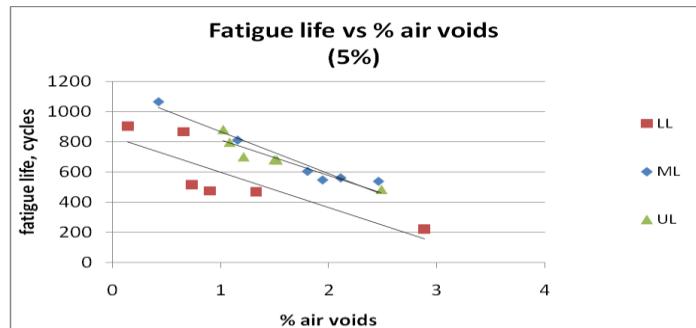


Figure 4: Fatigue Life Vs % Air Voids for NRMB Mix at 5% BC

### Fatigue Model

The values of fatigue life and initial strain can also be correlate using Phenomenological approach. This approach is useful in the process of crack initiation. It considers a load control or deflection control mode which correlates the number cycles to the applied stress or strain. Here the correlation between fatigue life ( $N_f$ ) and Initial Strain ( $\epsilon_i$ ) as introduced by Pell (1987) is considered as:

$$N_f = K (1/ \epsilon_i)^n \quad (4)$$

Where  $N_f$  is the number of load cycles to failure,  $\epsilon_i$  is the initial tensile strain. Here  $K$  depends on material properties and  $n$  depends on slope of the curve. Both of them are empirical constants. The values for  $K$  and  $n$  at 4.5% and 5% binder content are given in the Table 8. High coefficient of determination indicates high reliability of fatigue equations.

Table 8: Fatigue Coefficients

Binder Content	Gradatio n	$N_f = K (1/ \epsilon_i)^n$		Coefficient of Determination ( $R^2$ )
		K	n	
<b>NRMB 60/70</b>				
4.5%	LL	$3.29 \times 10^8$	2.285	0.788
	ML	$4.47 \times 10^5$	1.125	0.929
	UL	$2.72 \times 10^6$	1.458	0.891
5%	LL	$5 \times 10^5$	1.182	0.852
	ML	$5.2 \times 10^4$	0.757	0.9
	UL	$7.5 \times 10^3$	0.414	0.526

From the study it is evident that percent air voids in bituminous mix has a significant effect on the fatigue life of the mixture and also the middle limit specimens are always showing the better results.

### CONCLUSIONS

The performance characteristics, with respect to common failures like fatigue cracking, rutting and moisture susceptibility of the Natural Rubber Modified Bituminous mix are obtained by conducting different performance tests. Considering the observations and analysis of the results the following conclusions are arrived.

- The OBC of NRMB based on the performance tests is 5%.
- The NRMB mix has excellent rut resistance.
- The % air void has significant impact on the fatigue life of the bituminous mix. As the % air void increases the

fatigue life decreases.

- The fatigue life increases with increase in the resilient modulus and it decreases with the increase in the initial strain.
- Linear regression equations are developed for relating the fatigue life and resilient modulus, fatigue life and initial strain and fatigue life and %air void.
- The fatigue life of the NBMB mix increased significantly when the rest period of 0.9 sec is introduced.
- In all the performance tests the aggregate gradation Middle Limit is showing higher values than that of the Lower Limit and Upper Limit.

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## REFERENCES

1. Anjan Kumar, Amarnath M, Veeraraghavan A, 'Effect of air voids on fatigue performance of asphalt mixture', ICPT Report, July 2008.
2. Awanti S. S, Amarnath M. S & Veeraraghavan A, 'Influence of modified Marshall compaction technique on engineering properties of polymer modified and neat bituminous concrete mixes', Bangalore University, 2006.
3. Geetha. S., John P. Z., 'Evaluation of Indirect Tensile Strength to Identify Asphalt Concrete Rutting Potential', West Virginia University, May 2004.
4. IRC SP: 53-2002, 'Guidelines on use of polymer and rubber modified bitumen in road construction' Indian Road Congress (IRC), 2002
5. Maria Castro, Jose. A. Sanchez, 'Fatigue and healing of asphalt mixtures: Discriminative analysis of fatigue curves', ASCE Journal of transportation, February 2006.
6. Piotr Radziszewski, 'Modified asphalt mixtures resistance to permanent deformations', Bialystok Technical University, Poland, October 2007.
7. Rao S. C. S., Craus J, Deacon J. A., Monismith C. L., 'Summary Report on Fatigue Response of Asphalt Mixtures', SHRP- A- 312, February 1990.
8. Ray Brown. E, Prithvi. S. K, Zhang J, 'Performance testing for hot mix asphalt', National Centre of Asphalt Technology, Alabama, November 2001.
9. Robert B, McGennis, Anderson R. M, Dr. Thomas W. K, 'Background of superpave asphalt mixture design and analysis', U. S Department of transportation, 1995.
10. Shivangi Gupta, Veeraragavan A., 'Fatigue behaviour of polymer modified bituminous concrete mixtures', Journal of the Indian Roads Congress, March 2009.
11. Steyn W. M, Verhaeghe B. M. J. A 'Assessment of the permanent deformation characteristics of a standard HMA

*mix*', CSIR Built Environment, Gauteng, May 2006.

12. Sunghwan Kim, Brain. J. Coree, '*Evaluation of Hot Mix Asphalt moisture sensitivity using the Nottingham Asphalt Test Equipment*', Iowa State University, July 2005.

